

WOOD-PLASTIC COMPOSITE HAVING IMPROVED STRENGTH

Cross-reference to Related Applications

5 This application is a continuation-in-part of U.S. Patent Application No. 09/833,470, filed April 12, 2001, currently pending, and this application is also a continuation-in-part of U.S. Patent Application No. 10/292,672, filed November 12, 2002, now pending; which is a divisional of 09/217,994, filed December 21, 1998, now U.S. Patent No. 6,527,532; which is a divisional of 08/940,397, filed October 1, 1997, now U.S. Patent No. 5,851,469; which is a continuation of 08/579,111, filed December 27, 1995, now abandoned, all of which are herein incorporated by
10 reference..

Background of the Invention

(1) Field of the Invention

The present invention relates to a wood-plastic composite and, more particularly, to composite material including a bonding agent which produces a composite material having
15 improved strength.

(2) Description of the Prior Art

Composite materials consisting of a mixture of wood particles in the form of sawdust and a thermoplastic material have been known for many years. The materials so formed may be used in many of the same applications as an all wood product but offer the advantages of
20 providing high resistance to rot, insects and moisture. These products can have the same workability as wood and are splinter-free. However, these materials do not exhibit the same physical characteristics as wood and therefore may not be used as structural members in some applications. The recent past has seen increased interest in composite material manufacture as a viable outlet for recycled post consumer thermoplastic materials. This interest has been spurred
25 by the prospect of environmental regulations mandating the recycling of these materials. Also valuable, ever-shrinking landfill space may be conserved if both spent sawdust and plastic material are reused rather than disposed.

Forming a wood-polymer composite into a final product has been accomplished using some of the techniques used for forming all polymer products, including extrusion. While the technology for extruding all polymer products is well-developed with fairly predictable results, the extrusion of a wood-thermoplastic composite material using recycled input materials is

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HENDERSON
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DUNNER LLP

1300 I Street, NW
Washington, DC 20005
202.408.4000
Fax 202.408.4400
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subject to much wider variance in the molecular makeup and physical characteristics of the input materials, depending on available sources of recycled material. Moreover, a wood-thermoplastic composite has unique melt flow characteristics which prevent the literal translation of polymer extrusion techniques for use in composite material extrusion.

5 The present invention is concerned with an extruded wood-thermoplastic profile. A profile is defined in this art as an article fabricated from the composite material, the article having a variable length and consistent cross section. As used herein, the term dimensional stability refers to the tendency of a finished profile of a wood-thermoplastic composite material to hold to predetermined cross-sectional dimensions along its entire length. There are particular
10 problems encountered with wood-thermoplastic profile extrusion that make control of the dimensional stability of the final product difficult. First, it is well known in thermoplastic extrusion that extrusion equipment and operating conditions must be closely matched to the material being extruded. For example, attempting to extrude a given thermoplastic such as polyethylene in equipment designed for a different type of thermoplastic such as polypropylene
15 will give extremely unsatisfactory results. In contrast, the same extruder is used to make a composite product utilizing a wide range of thermoplastic input materials. When fabricating a composite product using recycled thermoplastic input material, the nature of the thermoplastic material may change from one minute to the next requiring changes to process controls. The process can be unstable.

20 A second problem is the presence of volatiles in the wood component. Volatiles in the wood-thermoplastic mixture are heated in the extruder barrel and attempt to escape as the profile exits the die. This effect is referred to as foaming and can result in severe dimensional distortion (sagging, bending, bunching or stretching) of the profile. The kinds of volatiles that can be found in a wood-thermoplastic mixture typically include ordinary moisture, wood lignin, and
25 terpenes. Another problem arises from the portion of the wood component that is near the surface of the profile exiting the extruder. At the profile's high temperature, the wood component can oxidize as it is exposed to air, creating a burned appearance on the final product.

 Underlying and to some extent magnifying these problems is the tendency of any extruded material to experience a phenomenon called die swell. Die swell is the tendency of an extrudate to swell as it leaves the die due to the release of shear stresses built up in the extrudate as it travels along the extruder barrel and die surfaces. Shear stress develops between the

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HENDERSON
FARABOW
GARRETT &
DUNNER LLP

1300 I Street, NW
Washington, DC 20005
202.408.4000
Fax 202.408.4400
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extrudate and the die wall causing tears and roughness in the finished surface of the profile in addition to die swell. In ordinary polymer extrusion the shape of the opening at the die exit may have to be changed dramatically from the desired final shape in order to account for extrudate swelling.

5 Calibration processes have been developed for thermoplastics extrusion to ensure that the extrudate emerging from a die maintains a certain shape. Some of these techniques are described in Polymer Extrusion, C. Rauwendaal, (2d reprinted ed., 1990) at pp. 448-450. Calibration typically involves the use of some type of cooled sizing die to fix the shape of the extrudate. Calibration of thermoplastic extrudates typically requires exerting tension variable force on the
10 extrudate to literally pull it through the calibration device. This approach is unworkable for the present invention because a wood-thermoplastic melt lacks sufficient melt strength to undergo appropriate tension. The extrudate of the present invention must be pushed through the die assembly and requires a different approach to ensure dimensional stability.

Various techniques are known for extruding wood-thermoplastic composite materials.
15 U.S. Pat. No. 4,968,463 to Levasseur (the '363 patent) discloses a process for producing extruded or molded objects from waste containing plastic materials. The process includes the steps of preliminary physical treatment, drying if the water content of the initial materials is over about 8% by weight, preheating to a temperature of 80 degree(s) C. to 160 degree(s) C. (176 degree(s) F. to 320 degree(s) F.), mixing or kneading at a temperature of 120 degree(s) C. to 250 degree(s)
20 C. (248 degree(s) F. to 482 degree(s) F.) to form a paste, and injection molding or extrusion. The process also contemplates the addition of coloring and/or filling agents such as compost refuse, incineration plant cinders, old paper, ground rags or fines from household waste after the drying step. Levasseur also discloses the use of a water-cooled casing immediately after the die to cool the profile.

25 U.S. Pat. No. 5,217,655 to Schmidt discloses a process for preparing a composite product from an intake material incorporating commercial, municipal or industrial waste containing organic, plastic and fibrous material. The intake material is first granulated and sized and is then heated in three consecutive stages. The material is continuously mixed during the heating stages and reaches a final temperature of about 160 degree(s) to 204 degree(s) C. (320 degree(s) to 400 degree(s) F.). The heating and mixing steps are carried out under very high pressures to ensure encapsulation of the filler material by the plastic fraction. These high pressures are stated to

range from about 141 to about 492 kg/cm² (2,000-7,000 psi). The material may then be co-extruded with a reinforcement structure and formed into a final product using vacuum profile dies or compression molding. The patent discloses mist spray cooling tanks as a preferred method of cooling the final product.

5 U.S. Pat. No. 5,082,605 to Brooks et al. discloses a method for making a composite material comprising a discontinuous phase of cellulosic fiber encapsulated in a polymeric matrix. The method requires that cellulosic fiber and polymeric material be mixed while simultaneously being heated to an encapsulation point. The mixture consists of a discontinuous phase of cellulosic fibers encapsulated in a polymeric continuous phase. The mixture is then reduced
10 mechanically into smaller golf ball sized particles having a maximum dimension of about 3.8 cm (1.5 in). The resulting particles are then extruded into a homogenous mass while maintaining the particle temperature within the encapsulation range. The homogenous mass is then forced through an alignment plate to substantially align fibers in a flow direction and then through an extrusion die to form a composite extrudate.

15 U.S. Pat. No. 4,225,640 to Erb discloses a method for reclaiming thermoplastic material from municipal waste. The thermoplastic material is first separated from the municipal waste and is decimated into fragments of a particular size. In similar fashion fallen leaves are separated from other municipal waste and are shredded to a predetermined size. The size to which both components are decimated is measured by the ability of the fragments to pass
20 through a particular mesh opening. The fragments of thermoplastic material and leaf material are then mixed thoroughly and subject to sufficient heat and pressure so that the thermoplastic material coats and bonds to the surfaces of the leaf fragments. The unitary mass so formed is then permitted to set and cure to be formed into any desired shape. The patent discloses that a preferred shape is the form of particle boards of standard size. The patent also discloses that the
25 unitary mass may be extruded to form finished articles. The flow of the mixture through the extruder is preferably controlled to provide a desired orientation of the leaf fragments as they flow therethrough. Despite the presence of these prior art processes, it remains a challenge to consistently and accurately fix the dimensions of a continuously extruded profile composed of a wood-thermoplastic composite material.

There are wood-thermoplastic composite materials known in the art that have been used to form various articles, including decking materials. These have proven particularly economical

since these use recycled waste in the form of wood chips or sawdust and shredded plastics, such as plastic bags. When mixed together and melted, the composite material may be extruded in any number of desired shapes and sizes. In particular, the extruded composites have been formed into planks in sizes conventional in the lumber industry for use as deck flooring. These have proven quite satisfactory for this use, but have not been found satisfactory for use in the remaining structural portions of a construction such as a deck.

Specifically, these extruded shapes (lumber sizes) have not proven acceptable, when tested by generally acceptable and approved codes and standards, for use as posts, - railing components or joists in such constructions. This is because the extruded composites have not demonstrated acceptable levels of flexural strength, as commonly measured on a Modulus of Rupture (MOR) scale. Flexural strength has been limited because the thermoplastic used in the composites, or polyethylene, will not bond with the wood component of the composite. In essence, the wood is simply suspended in the hardened plastic. The addition of other known glues and binders has been attempted, but because of there lack of affinity to bond with polyethylene, such additives have proven unsuccessful.

To date, the only practical means to increase flexural strength has been to increase the strength of the thermoplastic in the finished composite item. This, of course, is substantially more expensive and leads to other problems when extruded in larger cross-sectional sizes such as 4 inch by 4-inch posts. Because of the nature of the melting and cooling process, the inner cores of larger items tend to crack and rupture, effectively destroying the profile.

Thus, there remains a need for a wood-plastic composite including a bonding agent which produces a composite material having improved strength while, at the same time, consistently and accurately fixes the dimensions of a continuously extruded wood-plastic profile composite material.

Summary of the Invention

The present invention is directed to an extruded wood-plastic profile. The profile includes: a wood component; a plastic component, the wood component and the plastic component being intermixed to form the profile body. A bonding agent is added for improving the adherence between the wood component and the plastic component. In the preferred embodiment, the bonding agent includes a thermoplastic component and at least one bonding site. In the preferred embodiment, the plastic component is a thermoplastic and further includes

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HENDERSON
FARABOW
GARRETT &
DUNNER LLP

1300 I Street, NW
Washington, DC 20005
202.408.4000
Fax 202.408.4400
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a dimensionally stable shell surrounding the profile body. Also, in the preferred embodiment, the thermoplastic material is substantially polyethylene having a melt index of less than about 2.

Also, in the preferred embodiment, the bonding agent thermoplastic component is a polyethylene having a melt index value greater than the melt index value of the plastic component of the profile. The bonding agent is made from a linear polyethylene. In the preferred embodiment, its melt index value is about 5. The at least one bonding site preferably is an anhydride, such as a-carboxylic acid anhydride and is chemically attached to the polyethylene. Maleic anhydride is one example. In the preferred embodiment, maleic anhydride is about 1 weight percent of the total bonding agent.

The wood-plastic composite of the present invention has a modulus of rupture of greater than about 1200 psi when tested according to ASTM D4761, Standard Test Methods for Mechanical Properties of Lumber and Wood-Base Structural Materials, and, in the preferred embodiment, the modulus of rupture is greater than about 2500 psi. The modulus of elasticity of the composite remains greater than about 4×10^5 psi since, in the preferred embodiment, there is no change when we increase the amount of bonding agent because the amount of bonding agent does not effect the modulus of elasticity as long as the total of the plastic content, plastic type and the bonding agent remain constant.

The present invention also includes an apparatus for making the extruded wood-plastic profile. In the preferred embodiment, the apparatus includes: an extruder for providing a heated plastic mass and a feeder upstream of the extruder for combining the wood component, the plastic component and the bonding agent into a single feed to form the heated plastic mass. In the preferred embodiment, the feeder includes: a wood component feeder; a plastic component feeder; a bonding agent feeder; and a feed hopper for combining each of the feeds into one.

The apparatus also includes a die assembly attached to the extruder and a cooling flume downstream from the die assembly. The cooling flume preferably is an enclosed cooling flume adapted to quench the profile with a non-reactive quenching medium, such as water.

In the preferred embodiment, the feeders are screw feeders and preferably are loss-in-weight feeders. The apparatus may include a wood component dryer upstream from the wood component feeder for reducing the moisture content of the wood component. The apparatus may also include a pre-heater on at least the plastic component feeder for improving mixing of the plastic component and the feed hopper may further includes a "stuffer". Finally, the apparatus

may include an additive feeder for supplying at least one of colorants, mildew inhibitors, insecticides, other fillers, antioxidants, LTV-light inhibitors and absorbers, blowing or foaming agents, polymer flow aids, slip, antiblock, and the like.

5 Accordingly, one aspect of the present invention is to provide an extruded wood-plastic profile, the profile including: a wood component; a plastic component, the wood component and the plastic component being intermixed to form a profile body; and a bonding agent for improving the adherence between the wood component and the plastic component. Alternatively, two or more different bonding agents may be mixed.

10 Another aspect of the present invention is to provide a wood-plastic composite, having a wood component and a plastic component, wherein the wood component and the plastic component are intermixed to form the wood-plastic composite, the wood-plastic composite having a modulus of rupture of greater than about 1200 psi when tested according to ASTM D476 1, Standard Test Methods for Mechanical Properties of Lumber and Wood-Base Structural Materials.

15 Still another aspect of the present invention is to provide an apparatus for making an extruded wood-plastic profile, the apparatus including: an extruder for providing a heated plastic mass; a feeder upstream of the extruder for combining a wood component, a plastic component and a bonding agent into a single feed to form the heated plastic mass; and a die assembly attached to the extruder.

20 One of ordinary skill in the art would appreciate that plastic or thermoplastic may consist of only a resin or polymer, or may comprise a resin or polymer also having any combination of additional ingredients, for example, plasticizer, colorants, and other working additives. One of ordinary skill in the art would also appreciate that bonding agent may also consist of only a resin, polymer, or plastic, or may comprise a resin, polymer, or plastic having any combination of
25 additional ingredients, for example, any number of different chemical compounds that improve the bonding between plastic and wood. However, it should be understood that the additional ingredients need not necessarily improve the bonding properties of the bonding agent, for example, various impurities may be present in the bonding agent.

These and other aspects of the present invention will become apparent to those skilled in the art after a reading of the following description of the preferred embodiment when considered with the drawings.

FINNEGAN
HENDERSON
FARABOW
GARRETT &
DUNNER LLP

1300 I Street, NW
Washington, DC 20005
202.408.4000
Fax 202.408.4400
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Brief Description of the Drawings

FIG. 1 is an exploded elevational section view of the die assembly of the present invention;

FIG. 2 is a sectional view taken through the enclosed cooling flume looking towards the water inlet section;

FIG. 3 is a sectional view of a preferred embodiment taken through the enclosed cooling flume looking away from the cooling medium inlet section;

FIG. 4 is a sectional view through a cooling flume illustrating the formation of a profile having a different cross sectional shape;

FIG. 5 is a sectional view through a cooling flume showing an alternative shape of the cooling flume passage;

FIG. 6 is an elevational section view of the die assembly of the present invention showing the extrudate formed thereby and the path of the cooling medium;

FIG. 7 is a sectional view of an alternative embodiment of the cooling flume using a collar at the cooling flume exit;

FIG. 8 is a graphical representation of the temperature histories of the skin and the core temperatures of a wood-thermoplastic profile as it travels through the die assembly of the present invention;

FIG. 9 is a schematic side elevational view of a feeder for the apparatus for making the extruded wood-plastic profile;

FIG. 10 is a graphical representation illustrating how the Modulus of Rupture and Modulus of Elasticity of the extruded wood plastic changes as the percentage of bonding agent varies;

FIG. 11 is a photograph of the surface of an extruded wood-plastic profile formed without a bonding agent; and

FIG. 12 is a photograph of the surface of an extruded wood-plastic profile formed according to the present invention with a bonding agent.

Description of the Preferred Embodiments

In the following description, like reference characters designate like or corresponding parts throughout the several views. Also in the following description, it is to be understood that

FINNEGAN
HENDERSON
FARABOW
GARRETT &
DUNNER LLP

1300 I Street, NW
Washington, DC 20006
202.408.4000
Fax 202.408.4400
www.finnegan.com

such terms as "forward," "rearward," "left," "right," "upwardly," "downwardly," and the like are words of convenience and are not to be construed as limiting terms.

Reference will now be made in detail to a preferred embodiment of the invention, an example of which is illustrated in the accompanying drawings.

5 Referring to FIG. 1, the die assembly of the present invention is shown generally at 10 and comprises a converging die means 12, a low friction insulating land section 14, and a cooling section shown generally at 15 and comprised of a cooling medium inlet section 16 and an enclosed cooling flume 18. The die assembly is fed a wood-thermoplastic extrusion mass from an extruder 100 to the entrance end 20 of the converging die means 12. While a single screw
10 extruder provides acceptable results, a vented counter-rotating conical twin screw extruder introduces less shear stress in the wood-then-noplastic mass, while producing a higher output. It has also been found that providing vacuum vents on the extruder results in significantly higher moduli of rupture and elasticity because of the removal of excess moisture and volatile wood gases. For instance, it has been found that both modulus of rupture and modulus of elastic
15 increased by an average of 67%; e.g., modulus of rupture increased from about 1,200 to about 2,000 and modulus of elasticity increased from 150,000 to 250,000. The converging die means 12 has an entrance end 20 and an exit end 22. In the converging die means 12 the extrusion mass is formed into an extrudate profile having a desired cross sectional shape. That shape can vary greatly from that of commonly used building lumber to more complex profiles such as C
20 channels and the like. Those skilled in the art will appreciate that the shapes and cross sections may also take on decorative forms such as decorative balusters, etc. Though the converging die means is shown as a single stage in FIG. 1, the scope of the present invention includes the use of multistage dies having a plurality of stages each of which may be provided with individual temperature control. Multistage dies permit the wood-thermoplastic mass to be heated under
25 exacting control during formation of the desired profile.

Although not pictured in FIG. 1, an exit land section may be included as an optional element of the converging die means. The land section contains a passage having substantially the same cross sectional shape as the exit end 22. The thickness of this section and accordingly the length of the passage therethrough may vary for about 0.375 in to about 1 in. For some profiles, it is believed that the exit land section reduces the abrasion wear on the insulating land section 14 described below.

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HENDERSON
FARABOW
GARRETT &
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1300 I Street, NW
Washington, DC 20005
202.408.4000
Fax 202.408.4400
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5 Secured to the exit end 22 of the converging die means 12 or optionally to the exit land section is a low friction, insulating land section 14. The land section 14 has a passage 24 therethrough and is adapted to receive the profile from the converging die means 12. The land section passage 24 has a cross sectional shape substantially similar to that of the exit end 22 of the converging die means 12 and therefore of the extrudate profile. Unlike the converging die means, the land section passage has a constant cross sectional shape along its entire length. The surface 13 of the land section passage 24 is a low friction surface intended to minimize the amount of drag and associated shear forces generated between the extrudate and the land section 14. In a preferred embodiment the land section has a thickness of about 9.5 to 25.4 mm (0.375 to 10 1 in). Particularly preferred is a thickness of about 12.7 mm (0.50 in).

The practice of the present invention includes particular selection of the material used in the land section 14 to take into account the two functions it serves. First, it provides a low friction land which it is believed helps to impart a shape memory to the extrudate profile. Second, it acts as a thermal insulator to separate the hot converging die means 12 from the much cooler cooling section comprised of the cooling medium inlet section 16 and the enclosed cooling flume 18. This thermal insulation function is significant because in the absence of the land section, the extrudate would have to be heated to an extremely high temperature to avoid becoming completely solidified and thus plugging the die assembly as soon as it exited the die and was cooled. Thus, the land section 14 is desirably constructed from a material having low 15 thermal conductivity, high heat resistance and low coefficient of thermal expansion. 20

An additional desirable property of any material used in the land section is the ability to withstand the abrasive nature of the surface of a wood-thermoplastic melt. It has been found that while some materials may possess the low friction characteristic, they have a very short service life because they are quickly abraded by the coarse wood-thermoplastic melt surface. By way of 25 example, a desirable material for use as a land passage surface coating is polytetrafluoroethylene (PTFE). PTFE has a low coefficient of friction in sliding contact with the melt of the present invention and has good thermal insulation properties. Use of this material, however, would require the frequent and uneconomical replacement of the land section. Addressing this problem, it has been found that a PTFE composite, Fluorosint(r), filled polytetrafluoroethylene resin will adequately perform the land section function. Fluorosint(r) filled polytetrafluoroethylene resin is a composite of PTFE and a synthetic mica filler which provides

improved wear resistance. However, Fluorosint(r) is not a preferred material for this function because of its cost.

It has been found that a preferred material for the practice of the present invention is the Thermalate H320 insulation product manufactured by Haysite Reinforced Plastics. This product is a fiberglass reinforced thermoset polyester composite having the desirable properties listed above. While normally utilized solely as a mold or platen insulator, in the practice of the present invention Thermalate is put to novel use as part of an extrusion die in direct contact with the extrudate and is used to impart a desired shape to the extrudate.

It will be apparent to those of ordinary skill in the art that variations and modifications can be made to the land section 14 of the present invention. Thus, it is intended that these variations be considered part of the invention provided they come within the scope of the appended claims and their equivalents.

Referring again to FIG. 1, there is secured to the land section a the cooling section 15 which in a preferred embodiment of the present invention includes a cooling medium inlet section 16 and an enclosed cooling flume 18. The inlet section 14 has an inlet section passage 26 therethrough and is adapted to receive the profile from the land section 14. Cooling medium channels 28 are disposed within the inlet section 16 and extend radially from the inlet section passage 26 to the outside edge of inlet section. (See FIG. 2). The cooling medium channels 28 direct the flow of a cooling medium through the inlet section 16 and to the inlet section passage 26 where the medium makes direct contact with the profile, commencing the quenching step of the present invention. It should be understood that although two cooling medium channels 28 are shown in FIG. 2, additional channels may be utilized as required. For example, additional channels may be provided for a large profile or if a multi-opening die capable of extruding more than one profile simultaneously were used. It is also desirable to provide a means for controlling cooling medium flow through the channels. In the practice of this invention, the inlet section passage 26 is always flooded with whatever cooling medium may be used. It should be noted that the profile exiting the land section 14 completely fills the land section passage 24 so as to prevent flow of the cooling medium discussed herein below from the inlet section passage 26 countercurrent to the profile.

The enclosed cooling flume 18 is secured to the inlet section 16 and has a flume passage therethrough in communication with the inlet section passage. The length of the flume will vary

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1300 I Street, NW
Washington, DC 20005
202.408.4000
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with the size of the profile being produced and the temperatures in the converging section 12. As a non-limiting example, for the extrusion of profiles having standard U.S. building lumber sizes (5/4X6, 2X4, 2X6) a cooling flume having a length of from about 1.22 to 2.13 in (4 to 7 ft.) would be used. The flume section passage 29 has a cross sectional shape identical to and the same size as that of the inlet section passage. In this preferred embodiment, both those passages 26, 29 have the same cross sectional shape as that of the land section passage. However, each of those passages are symmetrically larger than the land section passage 24. The cooling flume passage 29 is also flooded with the cooling medium during operation of the die assembly.

Turning to FIG. 2, there is shown a sectional view taken along line 2--2 in FIG. 1. Because the land section passage 24 is smaller than the inlet section and cooling flume passages 26, 29, a small portion of the land section material 14 is exposed to the inlet section passage 26 and to direct contact with the cooling medium. Thus the cooling medium will not only surround and cool the profile but will also cool the land section 14. The cooling medium travels from the inlet section passage 26 down the cooling flume 18 and exits with the profile at the flume exit 19. The cooling medium may then be recycled for later reuse. Because the cooling medium flows concurrently with the profile to be cooled, the cooling medium should desirably flow at a higher speed than that of the profile so as to create relative motion and heat transfer between the cooling medium and profile. If the cooling medium travels at the same speed or slower than the profile, the cooling medium may effectively become a thermal insulating blanket surrounding the profile. It is believed that turbulent flow provides the best heat transfer. From the time it enters the inlet section passage through most of its travel through the cooling flume, the profile is maintained in a totally airless, non-oxidizing environment completely submerged in the cooling medium.

FIG. 3 is a section view taken along 3-3 through the cooling flume 18 in FIG. 1. The profile 200 is centered within the cooling flume passage 29 which has a symmetrically larger shape than that of the profile. As a result an annulus 210 is defined between the cooling flume interior surface 220 and the profile 200. The annulus is flooded with the moving cooling medium which serves to support the profile 200 in the passage. In this preferred embodiment, the cooling flume passage may be sized to create an annulus having a constant width of about 3.18 mm (0.125 in) to 6.35 mm (0.25 in) in size. Depending on the size and shape of the profile

200 other annulus widths may be utilized as may be readily determined by one of ordinary skill in the art.

A particular advantage of this cooling flume arrangement is that the contact between the cooling medium and the profile takes place in a near frictionless manner. Prior art methods for cooling an extruded profile of either an all polymer or a polymer composite material typically utilize some kind of sizing die having a cooled casing. An example of this arrangement is illustrated in the '463 patent described above. The prior art methods have the disadvantage that a significant amount of back pressure can develop as a result of the high-friction, sliding contact between the profile and the walls of the sizing die. In the present invention the profile is quenched in contact with a cooling medium so as to generate essentially no back pressure and therefore essentially no friction.

The practice of the present invention also includes the extrusion of profiles having more complicated cross sectional shapes as illustrated in FIG. 4. A preferred method for extruding these more complex shapes is the use of a cooling flume interior surface 46 which matches the shape of the profile 42. Here a C-shaped annulus 44 is defined around a C-shaped profile. Each of the profile projecting members 43 are surrounded by constant width stream of cooling medium. A workable alternative, although less desirable cooling flume embodiment of the present invention is illustrated in FIG. 5. Here a C shaped profile 52 is shown positioned in a cooling flume 18 having a generally rectangularly shaped interior surface 56. The annulus formed by this embodiment does not follow the shape of the profile 52. Projecting members 53 may be subject to differential cooling due to the disparity in the size of the cooling medium streams on either side thereof. It is believed that the resultant uneven cooling even under near frictionless conditions could cause the projecting members 53 to curve inwardly or outwardly towards the sides of the cooling flume.

It should be recognized that at some point near the flume exit 19 (See FIG. 1) the profile 200 will no longer be submerged in the cooling medium. This is because in the preferred embodiment the end of the flume is open to the atmosphere. Accordingly, in order to maintain the profile submerged in the cooling medium for a given distance a somewhat longer cooling flume must be provided. Any cooling flume will therefore have an effective cooling length that is somewhat shorter than its actual length. However, using the annulus width specified above; effective cooling length should approach actual length. This characteristic of the preferred

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202.408.4000
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cooling flume embodiment depicted in FIG. 1 may be avoided by using the flume configuration shown in FIG. 7. There it can be seen that a collar 70 of resilient material has been fitted into the flume exit 19. The collar 70 has a passage therethrough to permit the profile 200 to pass but acts as a dam for the cooling medium 75. An outlet 72 allows the cooling medium 75 to exit the flume. In this alternative embodiment the collar 70 makes light contact with the profile so as to contain most of the cooling medium 75 in the flume 18. The collar 70 need not form a watertight seal and a small amount of leakage past the collar 70 is permissible to lubricate the profile 200. Preferably the collar 70 should be constructed of a resilient material that does not scar the profile. It is believed that the profile 200 may tend to abrade the resilient material so that the collar 70 will require periodic replacement.

In another embodiment not pictured, the direction of cooling medium flow could be reversed so that the cooling medium enters the cooling flume 18 near the outlet 72 in FIG. 7. This embodiment provides countercurrent flow along the profile through the cooling flume passage 29 and inlet section passage 26 exiting the cooling section through the cooling medium channels 28. The countercurrent flow would provide superior heat transfer from the profile as it travels through the cooling flume. This embodiment could also utilize the collar 70 to retain cooling medium 75 in the flume 18. However, that element could be eliminated by angling the cooling flume 18 upwardly so as to retain the cooling medium therein.

Although the inlet section 16 and the cooling flume 18 are shown as separate elements in FIG. 1, they may in fact be combined into a single piece. Moreover, the cooling flume 18 may be provided in sections as a method of adjusting the flume effective cooling length and as a method of simplifying the handling of the components of the die assembly.

Referring now to FIG. 6 the method of making a wood-thermoplastic composite material can be seen to include the step of forming a thermoplastic mass at a temperature above the melting temperature of the thermoplastic component; passing the mass through a converging die means to form a shaped extrudate profile having the cross sectional shape with at least a part of the die means is maintained at a substantially higher temperature than that of the mass; feeding the profile through a low friction, thermally insulating land section having the same cross sectional shape as the profile; and quenching the profile in a non-oxidizing fluid to form a substantially dimensionally stable outer shell around the profile with the shell at a temperature below the melting temperature of the thermoplastic component.

The wood-thermoplastic mass 110 is formed in the extruder 100 from a wood component and a thermoplastic component preferred sources and preparation of which are described below. The mass 110 is desirably provided at a temperature above the melting temperature of the thermoplastic component. If the thermoplastic component is not homogenous and contains sub-
5 components having differing melting points, then the mass 110 must be provided at a temperature above the melting point of polyethylene. This may be the situation if the source of the thermoplastic component is recycled material. For reasons discussed below, a very small portion of the thermoplastic material may be unmelted.

The practice of the present invention includes providing the wood-thermoplastic mass
10 110 at a temperature of about 166 AC to 177 C. (330 F. to 350 F. at the entrance end 20 of the converging die means 12. Temperatures outside this range may be utilized depending on the nature of the thermoplastic material as determined by one of ordinary skill in the art.

The wood-thermoplastic mass 110 is next passed through a converging die means 12 where it is formed into an extrudate profile having a desired cross sectional shape. At least a part
15 of the die means 12 is maintained at a temperature substantially higher than that of the mass 110. Desirably this high temperature point of about 232 C. to 316 C. (450 F. to 600 F.) is maintained closest to the exit end 22 of the die means 12. It is believed that forming the extrudate profile at these temperatures plasticizes the thermoplastic component to such a degree that shear stresses between the profile and the walls of the converging die means are greatly reduced. From the
20 converging die means 12 the profile 200 is fed to an abutting, low friction, thermally insulating land section 14. The land section passage 24 has a cross sectional shape substantially similar to that of the exit end 22 of the converging die means 12. The land section 14 serves to prevent heat conduction from the hot converging die means 12 to the cooling inlet section 16 and cooling flume 18. Thus the, land section permits the die means 12 to be very hot and the cooling section
25 15 to be very cold. It is believed that the land section imparts a cross sectional memory to the high temperature profile 200. The low friction quality of the land section passage surface 13 (See FIG. 1) addresses the tendency of the profile 200 to experience swelling as it exits any shaping or forming element by reducing the drag between the surface of the profile 200 and the surface of the land section passage 13. The materials described above for use in the land section offer very little resistance to the travel of the profile 200 therethrough.

After leaving the land section 14, the profile 200 is then quenched in a non-oxidizing environment to form a substantially dimensionally stable outer shell around the profile. In a preferred embodiment, the profile is quenched by a cooling medium 75 that is fed through the cooling medium channels 28 to the cooling section inlet passage 26. (See FIG. 1). The quenching continues as both the cooling medium 75 and the profile 200 travel through the cooling flume 18. The quenching step "freezes" the outside of the profile 200 to form a substantially dimensionally stable outer shell around the profile. The shell will have a temperature below the melting temperature of the thermoplastic component. Setting the outside of the profile 200 in this manner locks in any volatiles in the profile core. As discussed above these volatiles can consist of moisture or wood lignins which cause foaming and dimensional distortion as they attempt to escape the profile.

The quenching medium may be any fluid that does not react with either the wood component or the thermoplastic component. Preferably the quenching fluid should not cause any oxidation of the wood component and should not adhere to profile 200 in quantity after the quenching step. A sticky quenching fluid would require a costly extra step to remove the fluid from the surface of the profile 200. Ordinary tap water provided at household pressure is a preferred quenching fluid. The work of the quenching fluid is accomplished by sealing the profile from exposure to air and transferring heat away from the profile and not by any pressure exerted by the cooling medium on the profile.

It should be understood that with respect to the quenching step, the term "freezing" as used herein refers to the melting temperature of the thermoplastic component, i.e. lowering the skin temperature of the profile 200 sufficiently below the melting point of the thermoplastic component so that a hardened shell is formed. Once again if the thermoplastic component contains more than one sub-component, the quenching step must reduce the profile shell temperature to that below the lowest melting point of any of those materials. Thus the "freezing" temperature will vary with and be defined by the nature of the thermoplastic component and the profile being extruded. The core of the profile 200 will undergo some cooling during the quenching step depending on the size of the profile being extruded. It is believed that very small profiles may be frozen nearly completely from surface to core. Larger profiles may exit the cooling flume having a core temperature that is quite warm compared to the shell temperature. It

has been observed that satisfactory results may be achieved with large profiles exiting the quenching step having core temperatures as high as 149 C. to 177 C. (300 F. to 350 F.).

The essence of the present invention is illustrated in FIG. 8 which graphically illustrates a comparison of the profile skin temperature to core temperature during the practice of the present invention. The horizontal axis has been divided into sections corresponding to the elements of the die assembly of the present invention. The vertical axis represents the temperature of either the core or the skin of the profile 200 as the profile moves through the die in the direction of arrow 80. The melting temperature of the thermoplastic component, T_m , is shown as a horizontal reference line. Point 82 on the graph shows the temperature of the wood-thermoplastic mass at the end of the extruder barrel and the entrance end 20 of the converging die means 12. Curve A is the temperature profile of the skin region of the profile as it travels through the die assembly of the present invention. It can be seen that the skin temperature is raised above T_m in the converging die means 12 and remains constant at that elevated temperature through the land section 14. At the start of the quenching process in the inlet section 16, the profile skin temperature drops very quickly below T_m . That process continues as the profile 200 travels through the cooling flume 18. Temperature drop in the profile core is dependent on profile size. It is believed that small profile cores see temperature history represented by curve B whereas large profiles see the temperature history represented by curve C. Compared to large profiles, small profile cores are heated to a higher temperature in the converging die means 12 and are quenched to a lower temperature in the cooling section 15. Moreover, small profile core temperatures are more likely to be at or below the melting temperature of the thermoplastic material at the exit of the cooling flume point E.

It should be understood that FIG. 8 is intended to show relative temperature relationships compared to the melting temperature of the thermoplastic component, rather than any specific temperature. Although straight lines have been shown for simplicity, the actual temperature changes may define a series of curves as opposed to a collection of straight lines.

As stated herein above the die assembly and method of the present invention are desirably practiced using a wood component and a thermoplastic component. The potential sources for the wood component are extremely varied. Sources include but are not limited to chips from a lumber yard or paper manufacturing facility. A particularly preferred source is sawdust available from furniture or pallet manufacturers. Both hardwood and soft wood sources

are acceptable, however, a hardwood source is preferable. The wood component undergoes a size reduction step in a suitable means such as a hammer mill that renders the wood component to a preferable particle size of less than about 600 microns. The particle size can also be expressed in terms of the ability of the size reduced wood component to pass through a wire mesh sieve. In this case the particles should preferably pass through a size 30 mesh or smaller sieve. Prior to processing in the hammer mill the wood component is passed by a strong magnet to remove metal fragments which could cause equipment failure and result in costly repairs and downtime. Moreover, those fragments may generate sparks in the hammer mill and other areas of the production line creating a potential explosion hazard. The present invention contemplates but is not limited to the wood component leaving the hammer mill having a bulk density of about 288 to about 352 kg/m³ (18 to about 22 lbs/ft³). In a preferred embodiment the wood component has a bulk density of about 320 kg/m³ (20 lbs/ft³).

The thermoplastic component used in the present invention must be carefully selected on the basis of melting point and other physical properties. Preferably the thermoplastic component will have a melting point below about 150 C. (302 F.). The melting point of the thermoplastic material should be low enough so as not to require extrusion temperatures sufficiently high to cause degradation of the wood component. Exposing the wood component to high processing temperatures for extended periods may increase the volume of volatiles generated.

Another physical property that may be important to the selection of the thermoplastic component is melt index. Melt index is a well known parameter of thermoplastic materials and is defined as mass rate of material flow through a specified capillary under controlled conditions of temperature and pressure. Melt index is measured using the well known ASTM Method D 1238-90b, Condition 190/2.16. Typically thermoplastic materials having a low melt index have a higher molecular weight and materials having a high melt index have a low molecular weight. Materials having a relatively high melt index are generally less suitable for making a wood-thermoplastic composite because they can adversely affect final product strength and can make the extrusion process difficult to control. Preferred materials will have a melt index of 2 or less.

The practice of the present invention contemplates using a wide variety of thermoplastic materials. However, a preferred thermoplastic component is some type of polyethylene. The origin and type of polyethylene can vary from post consumer material to post industrial scrap. In all cases the thermoplastic material should be as clean, free of debris and free of organic material

as practicable. Wet material is generally unacceptable due to the large amount of heat required to eliminate the excess moisture. The present invention includes the use of high density polyethylene and low density polyethylene. In a preferred embodiment, the thermoplastic component is high density polyethylene. Sources of the thermoplastic component include post consumer recycled material such as used thermoplastic grocery bags and stretch wrap film. It is also possible to use off-specification polyethylene products not suitable for sale. Other potential sources of thermoplastic material include post-consumer recycled waste that has been cleaned and reduced to pellet form and virgin thermoplastic resin.

In the event that the method of the present invention is practiced using recycled thermoplastic materials, it should be understood that occasionally a very small quantity of high melting point plastic may escape the screening step and become part of the finished product. Examples of such plastics include polyethylene terephthalate (PET), nylon and the plastic used to strap bales of recycled thermoplastic material. The presence of these kind of items in quantities not exceeding 2% to 3% by weight will not affect the method or the physical properties of the finished product provided that they are reduced to a very fine size. Another source of recycled materials may be previously formed products that were samples or that failed to meet certain quality parameters and that have been subsequently ground up.

The thermoplastic component is desirably screened for metal fragments that could damage equipment. This screening is typically done by hand in combination with a metal detector. The thermoplastic component is then size reduced to uniform flakes of less than about 3/4 inch in size and having a relatively low bulk density. The thermoplastic component typically has a bulk density of about 48 kg/m^3 (3 lbs/ft^3) or less. However, other acceptable forms of the thermoplastic component could have a much higher bulk density. By way of non-limiting example, the bulk density of either virgin or recycled material then-noplastic pellets can be about 448 to about 560 kg/m^3 (28 to about 35 lbs/ft^3). After the size reduction step, the thermoplastic component is mixed with the wood component. The thermoplastic component and the wood component are preferably mixed to contain from about 65 weight percent wood component to about 40 percent wood component and from about 35 percent thermoplastic component to 60 percent thermoplastic component. In a particularly preferred embodiment of the present invention, a mixture of about 52 weight percent wood component/48 weight percent

FINNEGAN
HENDERSON
FARABOW
GARRETT &
DUNNER LLP

1300 I Street, NW
Washington, DC 20005
202.408.4000
Fax 202.408.4400
www.finnegan.com

thermoplastic component is used. In all cases the weight percent of the thermoplastic component should be 60 percent or less.

The novel die assembly and method for making a wood-thermoplastic composite material have many advantages over prior art processes. They permit the use of a very high temperature in the die means adjacent to a cold quenching means that forms a hardened shell around the profile. Flowing the cooling medium directly around and along the profile avoids the use of casing type devices that require sliding contact with the profile. Minimizing such sliding contact is extremely beneficial for minimizing the build up of internal stresses in the melt and drag between the melt and the walls of the casing. The present invention has the farther advantage of reducing volatile components before they can cause distortion or bubbling. Dimensional stability of the final product increases as the size of the profile decreases, but for even large profiles the improvements are dramatic. The greater heat content of large profiles may be addressed by increasing the length of the enclosed cooling flume 18 and/or increasing the flow rate of the cooling medium 75. In comparison to conventional calibration methods used for plastic extrusion, an additional advantage of the present invention is the lack of any back pressure in the cooling section 15. Typical calibration methods using a cooled casing such as that shown in FIG. 2 of the '463 patent generate a considerable amount of back pressure and frictional heat during use. The present invention includes providing the profile with a non-oxidizing, virtually friction-free environment in the cooling section 15. In the preferred embodiment, the profile is in very low friction contact with a cooling medium stream rather than the high friction, sliding contact with a casing.

The method of the present invention is also advantageous because it is very forgiving of momentary flow stoppages through the die assembly. During production it is not unusual to encounter minor flow interruptions due to, inter alia, downstream material handling problems. It has been found the present invention readily accommodates these problems without adversely affecting product quality and while avoiding creating solidly frozen "plugs" at the extruder exit.

The preferred embodiment described herein contains one passage in each die assembly component for the formation and quenching of a profile. However, for smaller profiles it is possible to have multiple passages so that more than one profile may be extruded simultaneously. Each component of the die assembly may be adapted for multiple profile extrusion.

FINNEGAN
HENDERSON
FARABOW
GARRETT &
DUNNER LLP

1300 I Street, NW
Washington, DC 20005
202.408.4000
Fax 202.408.4400
www.finnegan.com

A further aspect of the present invention is a feeder for an apparatus for making an extruded plastic profile. Shown generally as 300 in Figure 9, the feeder comprises a wood component feeder 312, a plastic component feeder 314, a bonding agent feeder 316, and a feed hopper 319 for combining the three feeds together. The feeders are screw feeders, meaning that the wood, plastic, and bonding agent components are mechanically moved by auger or screw means into the feed hopper 319. This ensures that the three components are transported in generally consistent volumes for inclusion in the final mix. One type of screw feeder that is satisfactory for bulk solid components of this type are weigh feeders. Desirably, the weigh feeders are loss-in-weight feeders. This means that the feeder system is so formed that the wood, plastic, and bonding agent components are mixed on the basis of a continuous weighing process. That is, a pre-established weight, or mass, of one component is mixed with a pre-established weight of another. The present invention, however, is not limited to a particular type of feeder. Those in the art will appreciate that other types of feeders such as belt feeders and bucket feeders also provide acceptable results.

To ensure that constant weights of components are fed into the extruder 315 from the hopper 319, some positive action is required. Therefore, a stuffer 322, is provided to push or tamp the composite mixture through the hopper 319 and into the extruder 315 where the components are melted together and ultimately shaped into a composite profile of any one of the desired shapes.

The wood component of the mix for the ultimate extruded plastic profile is subject to an inherent moisture content because of the natural affinity, or hydrophilic nature. Since this could adversely affect the consistency and quality of the extruded composite, the present invention includes a dryer 313 positioned just upstream of the wood component feeder 312. The dryer 313 effectively reduces the moisture content of the wood component to less than one percent by weight. One such wood component dryer is a Rotary Steam Tube Dryer, commercially available from Louisville Drying Machinery.

To ensure a uniform melt of the composite mixture and a higher volume extruder screw design, a preheater 317 is desirably provided upstream of the plastic component feeder 314. The preheater 317 conditions the plastic component so that, when subjected to the higher melting temperatures in the extruder 315, the wood and plastic components will be of an even temperature. The preheater is a VMEDS, available from Extrusion Tek Milacron.

Since the extruded plastic profile may be used in any of various constructions, including, for example, deck materials, it is desirable to provide some means for the addition of additives that will enhance the appearance of the final product, protect the product from deterioration, or both. Accordingly, an additive feeder 320 is provided for the selective addition of such additives as colorants, mildew inhibitors, insecticides, etc. Solid or liquid feeders may be used, and there may be multiple additive feeders.

Further to the aspects described hereinabove is an extruded wood-plastic profile comprising a wood component and a plastic component, wherein the wood and plastic components are intermixed to form a profile body. A bonding agent is added for improving the adherence between the wood component and the plastic component. The bonding agent including a thermoplastic component and at least one bonding site. Further, the finished profile surface is also substantially free of burned regions. The plastic component is substantially a thermoplastic and has a dimensionally stable shell surrounding the profile body. The dimensionally stable shell has a shell temperature less than the melting point of the thermoplastic plastic component. The melting point of the thermoplastic plastic component is less than about 150°C. The wood component of the wood plastic profile has a bulk density of between about 18 lbs/ft³ and 22 lbs/ft³ and is desirably about 20 pounds/ft³. The wood-plastic profile is comprised of between about 40 wt.% and 65 wt.% wood, and desirably about 52 wt.% wood. The wood component is comprised of a plurality of wood particles, wherein each of the wood particles has a particle size of less than about 30 mesh. The wood component is selected from the group consisting of hardwoods and soft woods, or may be just hardwood.

The plastic component of the profile is substantially comprised of thermoplastic materials having a melting point range. The plastic component comprises between about 97 wt.% and 98 wt.% thermoplastic material and is substantially polyethylene. Further, the plastic component has a melt index of less than about 2 and is comprised of flake-shaped plastic particles. Each of the flake-shaped plastic particles has a size of less than about 3/4 inches and a bulk density of less than about 3 lbs/ft³. Alternatively, the plastic component is comprised of pellet-shaped plastic particles, where the pellet-shaped plastic particles have a bulk density of between about 28 lbs/ft³ and 35 lbs/ft³. This corresponds to approximately 25 to 65 pellets per gram.

The wood-plastic profile may be formed in varying dimensions. For example, in one form, the profile has a thickness of about 1 1/2 inches and a width of between about 3 1/2 to 9

inches. It may have a thickness of about 1 inch and a width of about 5 1/2 inches. The wood-plastic profile is also formed with a thickness of about 3 1/2 inches and a width of about 3 1/2 inches, which is most suitable for use as deck rail posts. As a further example, the profile may have a thickness of between about 1 5/8 inches and 1 7/8 inches and a width of between about 1 5/8 inches and 1 7/8 inches and is suitable for use as a deck rail baluster.

Where the plastic component of the wood plastic profile is thermoplastic, the thermoplastic is preferably a polyethylene. The bonding agent is mostly polyethylene and has a melt index value greater than the melt index value of the plastic component of said body. The bonding agent component of the wood plastic profile has at least one bonding site, which in the preferred embodiment is an anhydride. The anhydride is a carboxylic acid anhydride, and desirably a maleic anhydride. The bonding agent is preferably about 2 wt.% of the wood plastic profile.

As seen below in Table 1, four different examples have been tested and rated on a scale of 1 to 3, with 3 being best, based upon three attributes: cost, modulus of rupture, and profile appearance. The modulus of rupture rating, as used in Table 1, is a measure of how the modulus of rupture exceeds building code requirements for deck railing systems; e.g., International Building Code (IBC) 2000, Chapter 17. These examples assume that the amount of plastic component remains constant.

Table 1

Example		Cost	M.O.R.	Profile Appearance	Overall Product Score
1	Low Density Polyethylene	3	1	3	9
2	High Density Polyethylene	2	3	1	6
3	Low Density Polyethylene with a Bonding Agent Unlike the Present	1	1	3	3

	Invention				
4	Low Density Polyethylene w/Bonding Agent of Present Invention	2	3	3	18

With respect to surface appearance, an unexpected result of the present invention is the reduction in surface voids in the extruded profile formed with a bonding agent. As best seen in Figure 11, the longitudinal axis of an extruded profile formed without bonding agent runs from left to right. When formed without the bonding agent of the present invention, a moderate level of voids were detected; e.g., a 1 ½ inch by .025 inch strip revealed 15 voids, or 10 voids per inch of width. On the other hand, Figure 12 is a photograph of an extruded profile formed with the bonding agent of the present invention. Only 2 voids were detected in the same size strip (1 ½ inch by .025 inch), or 1 1/3 voids per inch.

In the present invention, the wood component and the plastic component are intermixed to form said wood-plastic composite having a modulus of rupture of greater than about 1200 psi when tested according to ASTM D4761, Standard Test Methods for Mechanical Properties of Lumber and Wood-Base Structural Materials.

Desirably, the modulus of rupture is between about 1800 psi and 2500 psi. The modulus of elasticity is greater than about 5 X 10⁵ psi. Figure 10 graphically illustrates how the modulus of rupture and modulus of elasticity of the extruded wood plastic change as the percentage of bonding agent varies. The wood-plastic composite is formed as a profile body that is extruded.

Certain modifications and improvements will occur to those skilled in the art upon a reading of the foregoing description. By way of example, two or more layers could be coextruded to form the profile. Multiple extruders could also be arranged in series or in parallel. High intensity premixers could also be used. Further, the feed mixture could be pre-pelletizing prior to profile extrusion. Also, the bonding agent could well be predeposited on the wood portion of the mixture. It should be understood that all such modifications and improvements have been deleted herein for the sake of conciseness and readability but are properly within the scope of the following claims.

FINNEGAN
HENDERSON
FARABOW
GARRETT &
DUNNER LLP

1300 I Street, NW
Washington, DC 20005
202.408.4000
Fax 202.408.4400
www.finnegan.com